XMCD studies of uranium/iron multilayers

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Introduction

The combination of a soft magnetic element (e.g. iron) and an element such as uranium with a large spin-orbit coupling is expected to produce unusual magnetic properties. Although elemental U is nonmagnetic, there are many magnetic U-compounds whose magnetism is controlled by the Coulomb and exchange interactions, the crystal field, the spin-orbit coupling and hybridization. The large orbital moment of the 5*f* electrons, considered along with these interactions, gives rise to strong anisotropies of potential technological interest. This paper reports on XMCD studies of the magnetic properties of U and Fe in a series of U/Fe multilayers.

Methods and Materials

U/Fe multilayer samples were grown by DC sputtering. The range of layer thicknesses, determined by X-ray reflectivity is 9 to 40 Å for uranium and 9 to 34 Å for iron. See [1,2] for details of the growth and magnetic and structural characterisation. The XMCD measurements reported here were carried out at 10K and room temperature on the beamline ID12 at ESRF, employing applied magnetic fields (parallel and antiparallel to the incoming X-ray beam) of up to 1 T. Further details of the experimental method and analysis procedures are to be published [3].

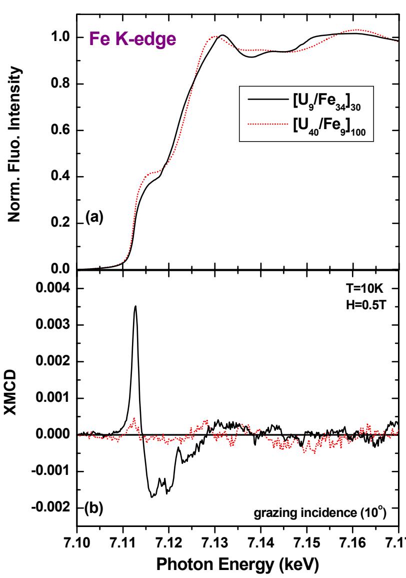

Fig. 1. Normalized XANES (upper) and XMCD (lower) spectra at the *K* edge of Fe for two U/Fe multilayers.

Results

Figures 1 and 2 present XANES and XMCD data for limiting members of the series of multilayers studied, namely the 30 repeat U(9Å)/Fe(34Å) and the U(40Å)/Fe (9Å) sample with 100 repeats, at the Fe *K* edge and U M_4 and M_5 edges, respectively.

Considering first the Fe *K* edge XANES, the spectra for the thin (9Å) Fe layer sample and that with much thicker (34Å) layers present a number of significant differences. For example, the pre-edge shoulder at 7.115 keV is much less marked while the maximum at the *K* edge lies about 2 eV lower, for the thin layer sample. These features are consistent with the presence of *textured bcc Fe* for thick Fe layers (above about 30 Å), while for thin Fe layers the XANES spectra correspond to *amorphous Fe*, consistent with Mössbauer results [1,2]. The Fe XMCD spectra are found to be as expected for bulk bcc iron.

The existence of the XMCD signal at the U edges confirms that the U atoms carry a magnetic moment [4]. For the 9 Å U layer sample, a full analysis of the XMCD data using the relevant sum rules [5,6] yields a value of 0.10 μ_B for the average induced moment in the U layers, arising from a *5f* spin moment of -0.08 μ_B and an orbital moment of 0.18 μ_B. The net moment is parallel to the Fe moment and decreases as the U layer thickness increases. The induced moment on the U atoms is located principally at the interfaces, although the exact nature of the U/Fe interfaces is uncertain (e.g. some degree of intermixing or a U-Fe alloy). A consideration of a set of four different multilayers of similar Fe layer thicknesses leads to a U-moment profile which drops rapidly to a very small value within each U layer. This profile resembles that observed for Ce/Fe multilayers [7]; however, in this latter case the Ce *5d* polarization is directed antiparallel to that of the iron layer.

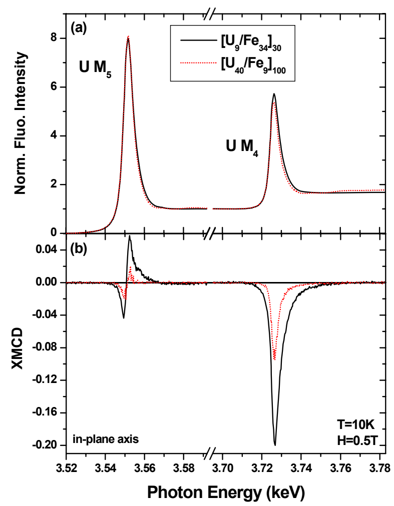

Fig. 2. As figure 1, at the U M_4 and M_5 edges

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